

Development of a monitoring program to assess physical, chemical
and biological components of Kaloko Fishpond at
Kaloko-Honokohau National Historical Park on the Island of Hawai'i

by

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SUMMARY

Among the notable features of Kaloko-Honokohau National Historical Park are two large fishponds; Aimakapaa Pond and Kaloko Pond. To protect and enhance both the cultural and biological value of Kaloko fishpond, the National Park Service has decided to restore the pond as a traditionally functioning Hawaiian fishpond. Restoration of the fishpond seawall and *makaha* (inlet/outlet structure or sluice gate) will result in changes to the current condition of the fishpond, potentially altering the habitat suitability of the pond for certain species.

The purpose of this project was to identify the critical resources of Kaloko fishpond and recommend a strategy to monitor these resources before, during, and after the re-establishment of the sluice-gate. This report will evaluate the resources in Kaloko Pond, summarize available data for biological, physical and chemical parameters, and discuss potential monitoring protocol. This report provides a description of the flora and fauna of Kaloko fishpond and summarizes data on water quality and biota collected during this and earlier (Bhambare 1997, Brock and Kam 1997, Brasher 1996, Chai 1991) studies. These survey results provide baseline information on the current, and past, status of Kaloko Pond, which future surveys can be compared to.

It is recommended that the strategy for monitoring critical resources include monitoring physical, chemical and biological parameters. While the final monitoring protocol must be based upon management decisions concerning methods of restoration and maintenance of the fishpond, suggestions for the initial monitoring strategy are summarized in this report. The focus of the monitoring should include physical (temperature, tidal fluctuation, and siltation), chemical (oxygen, pH, salinity, and conductivity) and biological (edible fish to be raised in the pond and rare invertebrates that may be affected by the planned restoration) components of the fishpond.

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INTRODUCTION

Kaloko-Honokohau National Historical Park, on the Kona coast of the Island of Hawai'i, was established in 1978 to protect the significant cultural resources of the area. Among the notable features of Kaloko-Honokohau National Historical Park are two large fishponds; Aimakapaa fishpond and Kaloko fishpond. To protect and enhance both the cultural and biological value of Kaloko fishpond, the National Park Service has decided to restore the pond as a traditionally functioning Hawaiian fishpond. The goal of this particular project was to identify critical resources associated with Kaloko fishpond and provide information to assist the Park in the development of an appropriate monitoring program.

This report will summarize the available data for biological, physical, and chemical parameters to provide baseline information on Kaloko Pond, and evaluate the current status of the pond's resources.

Kaloko-Honokohau National Historical Park

Kaloko-Honokohau National Historical Park is located along the Kona coast on the leeward side of Hualalai Volcano. A thriving Hawaiian settlement existed in Kaloko-Honokohau into the 19th century. In addition to the Park's value as a cultural resource, within the Park's boundaries is an extensive freshwater anchialine pond and fishpond system that is an outstanding biological resource. The fishponds, especially, highlight both the cultural and biological value of Kaloko-Honokohau National Historical Park.

Hawaiians developed the use of fish ponds, which served as an important supplement to their food source, to a greater extent than any other culture (Titcomb 1977). Fishponds played an important role in the life of the Hawaiian people, and great care was taken to keep the ponds intact, clean and clear of overgrowth. Part of the Park's mandate at Kaloko-Honokohau National Historical Park is the demonstration of historic land use patterns which includes the establishment and cultivation of the fishponds (Wyban 1996).

Monitoring of Critical Resources at Kaloko Fishpond

Kaloko-Honokohau National Historical Park is notable for preserving the cultural and traditional links of native peoples to the seas, and demonstrates the importance of fish culture and traditional fishing to the cultural and religion aspects of everyday life in ancient Hawai'i. Kaloko fishpond was used by native Hawaiians to rear such species as striped mullet or *ama'ama* (*Mugil cephalus*), silver perch or *aholehole* (*Kuhlia sandvicensis*) and milkfish or *awa* (*Chanos chanos*) for religious and subsistence purposes. With the restoration of Kaloko Pond as a functioning fishpond, a monitoring program focussed on these edible fish species should be developed.

Kaloko fishpond is a natural embayment approximately 11 acres in size, separated from the sea by a man-made sea wall (*kuapa*). The original sea wall was nearly 750 feet long and 35 feet wide (Kikuchi and Belshe 1971). The main pond has a roughly rectangular shape with an inlet on the southeast corner forming a tapering appendage. The pond is approximately 7 meters deep in the deepest areas.

Recent archaeological studies at the fishpond have described the design and structure of the pond and its seawall. Kaloko fishpond is an example of a stone wall enclosure type fishpond (*loko kuapa*). A *makaha* (entrance) allowed fish to enter the pond during high tide. The *pani*

(gate) was then closed, providing a food source year round. Restoration of these structures has been given a high priority by park management (Wyban 1996).

Restoration of the fishpond seawall and *makaha* (inlet/outlet structure or sluice gate) will result in changes to the current condition of the fishpond, potentially altering the habitat suitability of the pond for certain species. Expected changes include an increase in salt-water circulation which could result in a decrease in sedimentation (Ertekin et al. 1996) and also an increase in salinity (Bhambare 1997). As part of the monitoring program at Kaloko fishpond, physical and chemical data including temperature, salinity and dissolved oxygen concentration should be collected.

Potential Sources of Alteration to Kaloko Fishpond

In addition to the potential changes in Kaloko fishpond as a result of restoring the function of the sluice gate, other sources of impact to the pond need to be considered. The freshwater component of the pond results from groundwater flowing downhill (through lava tubes), eventually percolating to the surface near the shoreline. Both water quantity and water quality of the pond may be affected by *mauka* (uphill) activity which could impact the groundwater entering Kaloko Pond. Potential

development of the nearby Kohanaiki area should also be closely watched, and consideration given to any impacts that this development may cause to the Kaloko ecosystem.

Restoration of Sluice Gate

Opening the sluice gate will result in increased salt water circulation into, and within, the fishpond. An increase in salinity may make the pond more suitable for true marine species, and less suitable for those estuarine species that require relatively fresh water. Likewise, the increases in temperature with more sea water may alter the habitat suitability of the pond. Opening the sluice gate may also make the pond more accessible to certain marine species. All of the above have the potential of changing the species composition of the pond. Because Kaloko fishpond currently provides habitat for rare native invertebrate species (including snails, shrimp and damselflies), distribution and abundance of these "anchialine" fauna should be part of the monitoring program following the restoration of the fishpond. Both the increase in salinity and an increase in predatory marine fish, with additional ocean water circulating in the pond, could potentially affect these native invertebrates.

Mauka Development

Current information suggests no negative impacts of *mauka* (uphill) activities on water quality of the anchialine resources at Kaloko-Honokohau National Historical Park (Brock and Kam 1997). However, development activities could result in increased nutrient levels (such as from sewage or fertilizer) or contaminants in the groundwater, which would eventually reach the fish pond. A second scenario of *mauka* development that may affect Kaloko fishpond is a potential change in the quantity of groundwater flowing to the fish pond. Pumping in wells in the *mauka* area could potentially decrease the amount of groundwater available. Less fresh water moving into the pond would have similar impacts as an increase in seawater entering the pond with the restoration of the *makaha*. If both were to occur simultaneously, the freshwater component of the fishpond could be drastically reduced. Two wells which can be used to monitor water quality, including salinity (or relative contribution of freshwater and saltwater) and contaminants are currently located directly uphill of Kaloko fishpond. Utilization of information from these two wells could provide valuable information as part of a monitoring program at Kaloko fishpond.

FLORA AND FAUNA OF KALOKO FISHPOND

Riparian vegetation

The vegetation of Kaloko-Honokohau has been severely modified by the invasion of alien plants, and no longer reflects the vegetation prior to, or even during, Hawaiian occupation. During the early eighties, introduced red mangrove (Rhizophora mangle) was such a pest that it encircled the entire pond. One result of this was the elimination of valuable nesting habitat for important native waterbirds (M. Morin, personal communication). In 1992, following a four-year experimental phase, the Park was able to eradicate the mangrove from the area surrounding the fishpond. Subsequently, alien pickleweed (Batis maritima) became a significant weed on the shores of the pond, and the Park Service is currently evaluating methods for its removal.

Riparian vegetation was not the focus of this study, however, an excellent description of plant species in Kaloko-Honokohau National Historical Park is provided by Pratt and Abbott (1996). The predominant indigenous plants surrounding the pond included 'akulikuli (Sesuvium portulacastrum), 'ilima (Sida fallax), kipukai (Heliotropium curassavicum) and naio (Myoporum sandwicense). Less common were pohuehue (Ipomoea pes-caprae) and 'uhaloa (Waltheria indica). The Polynesian

introduction, *noni* (*Morinda citrifolia*), was also common around Kaloko pond.

Birds

The fishponds, tidal areas and wetlands at Kaloko-Honokohau National Historical Park serve as valuable habitat for many waterbirds, including two endangered species, the Hawaiian Stilt or *ae'o* (*Himantopus mexicanus knudseni*) and the Hawaiian Coot or '*alae ke'oke'o*' (*Fulica alai*). The indigenous Black-Crown Night Heron or *auku'u* (*Nycticorax nycticorax*) also utilizes this area. While both the stilt and Black-Crown Night Heron have been observed at Kaloko fishpond, the coot has not. During this project up to 11 stilts were observed at any one time on Kaloko Pond, primarily in the shallow silted area that will be restored to hold fish.

Morin (1996) provides a thorough inventory and discussion of the avifauna of Kaloko-Honokohau National Historical Park, and has studied the outbreak of avian botulism at Aimakapaa Pond at the southern end of the Park (Morin, 1994). Although the purpose of this current project was not to monitor birds, we did note when they were present. In addition to the endemic stilt and indigenous Night Heron, the only other native bird observed at the pond during this study was the indigenous Wandering Tattler or '*ulili*' (*Heteroscelus incanus*). Introduced (or alien) birds observed

at Kaloko fishpond included the Myna (Acridotheres tristis), Northern Cardinal (Cardinalis cardinalis) and Yellow-billed Cardinal (Paroaria capitata).

Predators such as mongoose, feral cats, and dogs present a threat to the water birds and are believed to be responsible for poor nesting success rates. During our survey we noted a feral cat near the northern shore of the pond, and numerous mongoose. It is also a common practice for visitors to bring pet dogs, which owners sometimes allow to run loose in the Park.

Fish

The results of three surveys (Chai 1991, Brasher 1996, and the present survey) provide a comprehensive baseline of the aquatic species, both fish and invertebrates, found in Kaloko fishpond. Additional observations on the biota were reported by Maciolek and Brock (1974) and Brock and Kam (1997). Fish were surveyed using a number of methods including gill nets, seines, dip nets, traps, hook and line, and visual observation with mask and snorkel or from the shore.

Kaloko Pond provides habitat for both marine and estuarine fishes (Table 1). Like most estuaries, Kaloko Pond serves as a nursery for juvenile marine species. For example; Chai (1991) reported a school of young *ulua* (Caranx ignobilis) and we observed a school of young *akule*

(Trachiurops crumenophthalmus). Traditional fishpond species including milkfish or awa (Chanos chanos), mullet or ama'ama (Mugil cephalus) and flagtail or aholehole (Kuhlia sandvicensis) were common in Kaloko fishpond. Introduced minnows (Poeciliidae) were reported in the earlier studies and included guppies (Poecilia reticulata) (Chai 1991, Brock and Kam 1996), mollies (Poecilia vittata) and mosquito fish (Gambusia affinis) (Brasher 1996). Interestingly, no introduced minnows were trapped or even observed in Kaloko Pond during this survey (conducted between October and December 1997).

FISH IN KALOKO FISH POND

Scientific name	Common name	1991*	1996**	1997
ACANTHURIDAE	SURGEONFISH			
<i>Acanthurus sandvicensis</i>	manini	X		X
CANTHIGASTERIDAE	PUFFER			
<i>Canthigaster amboinensis</i>	pu'u o la'i	X		
CARANGIDAE	JACK			
<i>Caranx ferdau</i>	papio	X		
<i>Caranx ignobilis</i>	ulua	X		
<i>Scomberoides sanctipetri</i>	lai	X		
<i>Trachiurops crumenophthalmus</i>	akule			X
CHAETODONTIDAE	BUTTERFLY FISH			
<i>Chaetodon lunula</i>	kika kapu	X		X
CHANIDAE	MILKFISH			
<i>Chanos chanos</i>	awa	X		X
DIODONTIDAE	PORCUPINEFISH			
<i>Diodon hystrix</i>	kokala			
ELEOTRIDAE	SLEEPER			
<i>Eleotris sandwicensis</i>	o'opu akupa	X	X	X
ENGRAULIDAE	ANCHOVY			
<i>Stolephorus purpureus</i>	nehu	X		X
GOBIIDAE	GOBY			
<i>Bathygobius cocosensis</i>	o'opu	X	X	X
<i>Oxyurichthys lonchotus</i>	o'opu	X	X	X
HOLOCENTRIDAE	SQUIRREL FISH			
<i>Sargocentron xantherythrum</i>	ala 'ihi	X		
KUHLIIDAE	FLAGTAIL			
<i>Kuhlia sandvicensis</i>	aholehole	X	X	X

Table 1a. Fish observed in Kaloko fishpond during three surveys: *1991 (Chai), **1996 (Brasher) and 1997 (current survey). Only the SE corner of the pond was surveyed during 1996. Table continued next page.

FISH IN KALOKO FISH POND

Scientific name	Common name	1991*	1996**	1997
LABRIDAE	WRASSE			
<i>Stethojulius balteata</i>	omaka	X		
<i>Thalassoma duperreyi</i>	hinalea lauili	X		X
<i>Thalassoma sp.</i>	hinalea	X		X
MUGILIDAE	MULLET			
<i>Mugil cephalus</i>	ama 'ama	X	X	X
MULLIDAE	GOATFISH			
<i>Mulloides flavolineatus</i>	weke	X		
MURAENIDAE	MORAY EEL			
<i>Echidna nebulosa</i>	puhi kapa	X		X
<i>Gymnothorax sp.</i>	puhi kapa	X		X
POECILIIDAE	MINNOWS			
<i>Gambusia affinis</i>	mosquito fish		X	
<i>Poecilia vittata</i>	molly		X	
<i>Poecilia reticulata</i>	guppy	X		
POLYNEMIDAE	THREAD-FIN			
<i>Polydactylus sexfilis</i>	moi			X
POMACENTRIDAE	DAMSELFISH			
<i>Abudefduf abdominalis</i>	mamo	X		X
<i>Abudefduf sordidus</i>	kupipi	X		X
SCARIDAE	PARROT FISH			
<i>Callyodon sp.</i>	uhu	X		
SERRANIDAE	GROUPE			
<i>Cephalopholis argus</i>	roi	X		X
SPHYRAENIDAE	BARRACUDA			
<i>Sphyrna barracuda</i>	kaku	X		X
TETRADONTIDAE	PUFFER			
<i>Arothron hispidus</i>	o'opu hue	X		

Table 1b. Fish observed in Kaloko fishpond during three surveys: *1991 (Chai), **1996 (Brasher) and 1997 (current survey). Only the SE corner of the pond was surveyed during 1996. Table continued from previous page.

Invertebrates

Anchialine pond systems, and the related fishponds at Kaloko-Honokohau National Historical Park, support a wide variety of invertebrates including endemic species especially adapted to this unique mixing of fresh water and salt water. Some of these native invertebrate species are currently under consideration for listing as threatened or endangered with the U.S. Fish and Wildlife Service. Baseline information on invertebrate species composition is provided by three surveys; Chai (1991), Brasher (1996) and the current study (Table 2).

Aquatic invertebrates were collected with traps, dip nets and by hand.

Taxonomy of anchialine and freshwater invertebrates in Hawai'i is currently under revision. In addition, many less common species may be difficult to detect or identify. For example, the rare nocturnal snail Neritilia hawaiiensis has been reported in ponds along the Kona Coast (C. Unabia, personal communication) including Kaloko fishpond, and the rare epigeal shrimp Palaemonella burnsi was recorded from Kaloko Pond in a survey by Maciolek and Brock (1974) but not since. Likewise adult odonates (dragonflies and damselflies), including the rare endemic damselfly Megalagrion xanthomelas, have been observed at many anchialine locations in Kaloko-Honokohau National Historical Park (D. Foote, personal communication). Consequently, it is expected that the list of

invertebrates in Kaloko fishpond presented here may be expanded in the future.

The sea wall (*kuapa*) itself contains numerous additional invertebrate species such as *ina* or rock-boring urchins (*Echinometra mathaei*), brittle stars (*Ophiocoma pica*), and mussels (*Brachidontes cerebristriatus*). Such species are common along the Kona coastline, and changes to the fishpond are not expected to impact them. As in earlier surveys, the boundary for fauna surveyed in this study was arbitrarily set where the environment became entirely marine, and the reef and tidepool fauna located on the sea wall will not be further discussed in this report.

INVERTEBRATES IN KALOKO FISH POND

Scientific name	Common name	1991*	1996**	1997
ANTHOZOA	SEA ANEMONE			
<i>Aiptasia pulchella</i>		X		X
CRUSTACEA	SHRIMP AND CRABS			
<i>Alpheus crassimanus</i>	snapping shrimp			X
<i>Macrobrachium grandimanus</i>	opae oe'aha			X
<i>Metaporgrapsus thukuhar</i>	a'ama	X	X	X
<i>Palaemon debilis</i>	opae huna	X	X	X
DEMOSPONGIAE	SPONGE			
<i>Haliclona sp.</i>	encrusting purple	X		X
HOLOTHUROIDEA	SEA CUCUMBER			
<i>Actinopyga mauritiana</i>		X		X
<i>Holothuria atra</i>		X		X
POLYCHAETA	WORM			
<i>Eurythoe complanata</i>	fire worm	X		X
MOLLUSCA	SNAIL AND BIVALVES			
<i>Nerita picea</i>	pipipi			X
<i>Isognomen</i>	oyster	X		X
<i>Tellina palatam</i>	clam	X		
<i>Theodoxus cariosus</i>	hapawai	X	X	X
<i>Thiaridae</i>	snail	X		X
<i>Serpulorbis variabilis</i>	tube snail			X

Table 2. Invertebrates observed in Kaloko fishpond during three surveys: *1991 (Chai), **1996 (Brasher) and 1997 (current survey). Only the SE corner of the pond was surveyed during 1996.

PHYSICAL AND CHEMICAL CHARACTERISTICS

A characteristic feature of the Kona Coast is its diffuse groundwater discharge at the shoreline (Brock et al. 1978). The cooler, lighter fresh water floats on the salt water layer. The brackish water of Kaloko fishpond is the result of groundwater moving seaward through the porous substrate and mixing with warmer, more saline waters below. Winds create waves on the surface of the water which help the mixing process (Bhambare 1997). Since groundwater and seawater show different water quality characteristics, water quality in the pond should reflect the relative influence of seawater versus freshwater at a given tidal condition (Brock et al. 1978).

A number of water quality characteristics considered to be indicative of freshwater versus saltwater were measured at Kaloko fishpond during this study. Water temperature ($^{\circ}\text{C}$) and pH were measured using an Orion Model 250A pH meter. Conductivity and salinity were measured using a YSI Cond/Salinity Meter. Dissolved oxygen concentration (ppm) was determined using a YSI Model 54 Dissolved Oxygen Meter. Measurements were made just below the surface and at 30 cm from the bottom. When the water was deeper than 150 cm at a given station, an additional measurement was made at 100 cm from the

surface. pH measurements could only be made to a depth of 125 cm due to the length of the cord attached to the probe.

Measurements were taken across a North-South transect and an East-West transect, and also in the South-East corner of the pond (Figure 1). Two kayaks were required to carry the water quality meters. At each sampling station an anchor was gently lowered to the bottom of the pond to prevent the kayaks from drifting substantially as meter readings were being determined. Water quality characteristics were measured during the high tide of 16 cm (6 pm) on 12/15/97 (Table 3) and the high tide of 60 cm (6am) on 12/16/97 (Table 4). It took approximately three hours to measure all of the parameters at all of the stations on the pond.

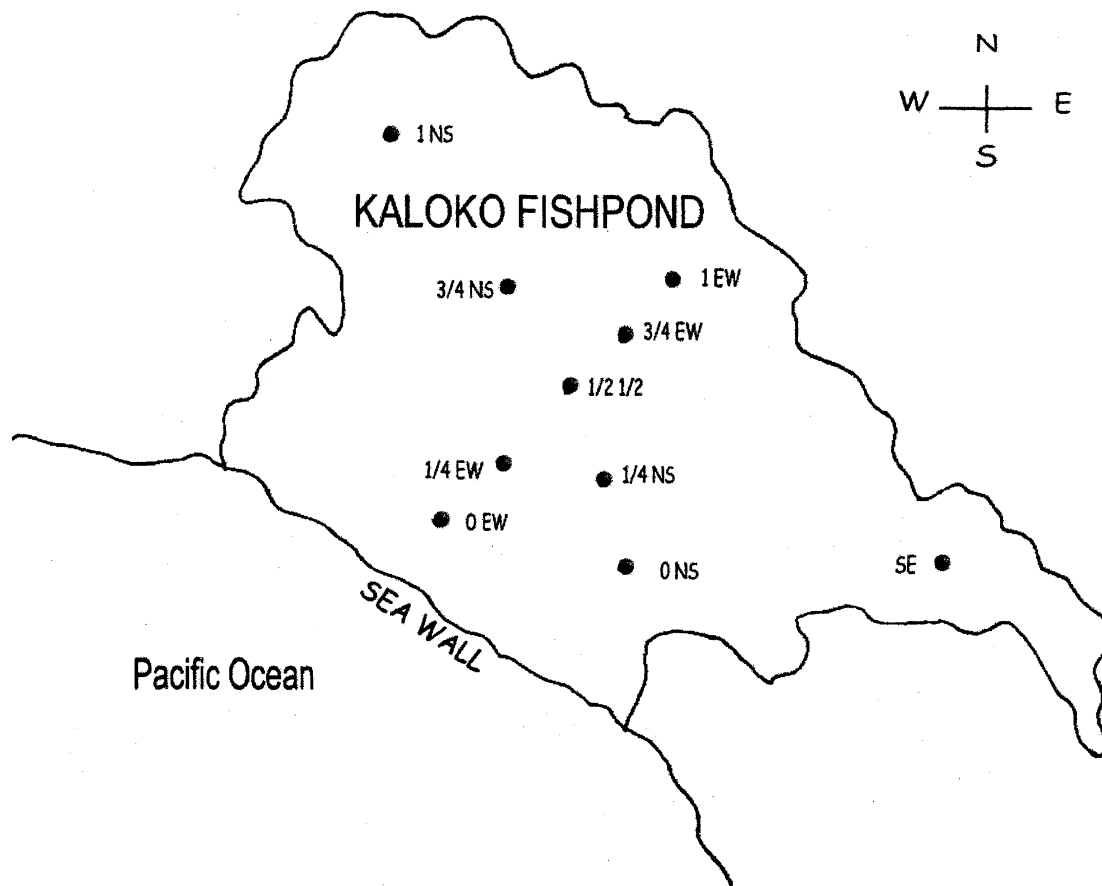


Figure 1. Location of water quality sampling stations on Kaloko Pond.

WATER QUALITY CHARACTERISTICS AT KALOKO POND

12/15/97 6PM

STATION	ONS	1/4EW	0EW	1/2-1/2	3/4NS	1NS	1/4NS	3/4EW	1EW	SE
DEPTH (cm)	105	159	248	323	147	165	313	204	82	117
TEMPERATURE										
SURFACE	26.6	25.7	25.3	26.5	25.1	25.9	26.7	26.3	26.5	27.2
MID (1 M DOWN)		26.4	26.6	26.4		26.5	26	26.4		
BOTTOM (30 CM UP)	26.8	26.1	26.4	26.5	26.5	26	26.4	26.4	27.3	26.8
pH										
SURFACE	8.18	8.1	8.2	8.21	8.29	8.17	8.21	8.23	8.24	8.13
MID (1 M DOWN)		8.16	7.6	8.2		8.16	na	8.17		
BOTTOM (30 CM UP)	8.16	na	na	na	8.19	na	8.2	na	8.19	8.13
CONDUCTIVITY										
SURFACE	480	470	410	462	440	450	>500	450	380	485
MID (1 M DOWN)		>500	>500	>500		>500	>500	>500		
BOTTOM (30 CM UP)	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500
SALINITY										
SURFACE	29.5	30	26	30	26	29	30	25	22	31
MID (1 M DOWN)		33.5	32	33		33	32	33		
BOTTOM (30 CM UP)	31	33.5	32.5	33	33.5	33	32.5	33	33	33
DISSOLVED OXYGEN										
SURFACE	6.9	6.4	6.6	7.2	6.6	6.9	6.6	7.2	8	7.2
MID (1 M DOWN)		6.4	7.2	7.4		7.4	6	6.5		
BOTTOM (30 CM UP)	7	6.9	6.7	6.3	7.9	6.5	6.7	6.8	7.9	6.4

Table 3. Water quality characteristics at Kaloko fishpond on 12/15/97.

WATER QUALITY CHARACTERISTICS AT KALOKO POND

12/16/97 6AM

STATION	0NS	1/4EW	0EW	1/2-1/2	3/4NS	1NS	1/4NS	3/4EW	1EW	SE
DEPTH (cm)	124	246	142	341	213	240	318	340	163	131
TEMPERATURE										
SURFACE	25	25	25	25	25	25	25	25	25	25
MID (1 M DOWN)		25		25	25	25	25	25	25	
BOTTOM (30 CM UP)	26	25	25.2	24.8	25.2	25.9	25.7	25.3	26	25
pH										
SURFACE	8.1	8.19	8.25	8.2	8.34	8.2	8.17	8.22	8.07	8.17
MID (1 M DOWN)		8.14		8.14	8.17	8.17	8.1	8.19	7.93	
BOTTOM (30 CM UP)	8.09	na	7.7	na	na	na	na	na	na	8.12
CONDUCTIVITY										
SURFACE	460	420	425	350	450	420	350	435	430	490
MID (1 M DOWN)		>500		>500	>500	>500	>500	>500	>500	
BOTTOM (30 CM UP)	>500	>500	>500	>500	>500	>500	>500	>500	>500	>500
SALINITY										
SURFACE	29	26	27	23	28	25.5	22	29	28	29
MID (1 M DOWN)		32		32	32	32	32.5	33	33	
BOTTOM (30 CM UP)	32.5	32	33	32.5	32.5	31.5	33	33	33	33
DISSOLVED OXYGEN										
SURFACE	4.8	5.2	5.8	5.9	5.8	5.1	5.6	5.9	5.9	6.2
MID (1 M DOWN)		5.5		5.3	5.7	5.5	5.7	5.9	6.1	
BOTTOM (30 CM UP)	4.4	5.3	5.1	5	5.3	5.4	5.2	5.4	5.2	5.5

Table 4. Water quality characteristics at Kaloko fishpond on 12/16/97.

A more extensive evaluation of the water quality characteristics at Kaloko fishpond was conducted in November 1995 (see Bhambare 1997 for complete details of methodology and results). During the 1995 study, salinity ranged from 11.5 to 31.5‰, temperature from 26 to 32 °C, dissolved oxygen from 4.4 to 13.07 mg/l, and pH from 8.5 to 8.7. The wide range of dissolved oxygen concentration reflected diel changes in solar radiation. At night, with the reduction in solar radiation was a large drop in dissolved oxygen concentration, while during the day photosynthesis resulted in the production of high levels of oxygen (Bhambare 1997).

Ground water is the major source of nutrients to the anchialine systems along the Kona Coast (Brock et al. 1978). Although measurement of nutrients was out of the scope of this project, baseline information is provided by Brock and Kam (1997) as part of a three-year study on the water quality characteristics of the anchialine system at Kaloko-Honokohau National Historical Park (Table 5).

Nutrients reported by Brock and Kam included: nitrate+nitrite (NO_3), ammonia (NH_4), total nitrogen (N), orthophosphorus (PO_4), and total phosphorus (P). These samples were collected at four sites on the pond: F1 (SE corner), F2 (surface, middle of the pond), F3 (bottom, middle of the pond) and F4 (southwest corner of the pond); and two wells W3 (just mauka of the pond) and W4 (mauka of W3).

NUTRIENT CHARACTERISTICS OF KALOKO FISHPOND

1994-1996 (from Brock and Kam 1997)

STATION		F1	F2	F3	F4	W2	W3
NO3	mean	21.44	0.41	0.1	0.38	82.73	75.66
	(sd)	(19.27)	(0.38)	(0.11)	(0.39)	(5.20)	(3.09)
NH4	mean	1.36	0.26	0.28	0.63	0.14	0.26
	(sd)	(0.70)	(0.31)	(0.14)	(0.43)	(0.14)	(0.30)
N	mean	32.23	11.21	8.66	9.51	89.7	83.19
	(sd)	(16.47)	(2.12)	(1.41)	(2.16)	(5.71)	(6.91)
PO4	mean	1.33	0.16	0.15	0.15	4.27	4.1
	(sd)	(1.16)	(0.08)	(0.08)	(0.08)	(0.16)	(0.29)
P	mean	1.63	0.55	0.52	0.45	4.38	4.3
	(sd)	(1.12)	(0.10)	(0.10)	(0.06)	(0.11)	(0.49)

Table 5. Nutrient concentrations measured at Kaloko Pond (F1 to F4) and two mauka monitoring wells (W2 and W3) during 1994-1996, as reported by Brock and Kam (1997).

DEVELOPMENT OF MONITORING PROTOCOL

Evaluation of Monitoring Methods

Water Quality

There are a number of basic approaches that have been used to assess water quality conditions in Kaloko fishpond. These include measuring groundwater in wells and surface water in the pond, using both field tests and laboratory analysis. Monitoring has been designed to

evaluate diel and seasonal changes in water quality characteristics, and especially tidal influence on water quality in the pond.

The present study supports findings by Chai (1991) that the pond is fairly well mixed, with salinities near that of seawater. This is reflected by the fact that purely marine species were observed in all areas of the pond. A 1971 study, however, indicated a much higher influx of freshwater than at present (Chai 1991). However, Bhambare (1997) reports a much wider range of salinities (11.5 to 31.5‰) in 1995 than found by Chai (1991) or during the present study (1997).

Overall, water chemistry results reported in earlier studies (Bhambare 1997, Brock and Kam 1997, and Chai 1991) are consistent with the measurements we made during this study, suggesting that the water quality of the pond has remained consistent over the last eight years. Bhambare (1997) found much higher variation in surface water measurements than those in deeper water and concludes that monitoring strategy will depend upon whether or not the pond has a continuous direct connection to the sea.

A plot of water quality characteristics (temperature, salinity, and dissolved oxygen) that are indicative of freshwater versus seawater shows there to be a freshwater layer overlaying a salt water layer, however, there is little difference in the parameters from the mouth (*makai*) to the

back (*mauka*) of the pond (Figure 3). The bottom of the pond was warmer, more saline and had lower levels of dissolved oxygen than the freshwater layer at the surface.

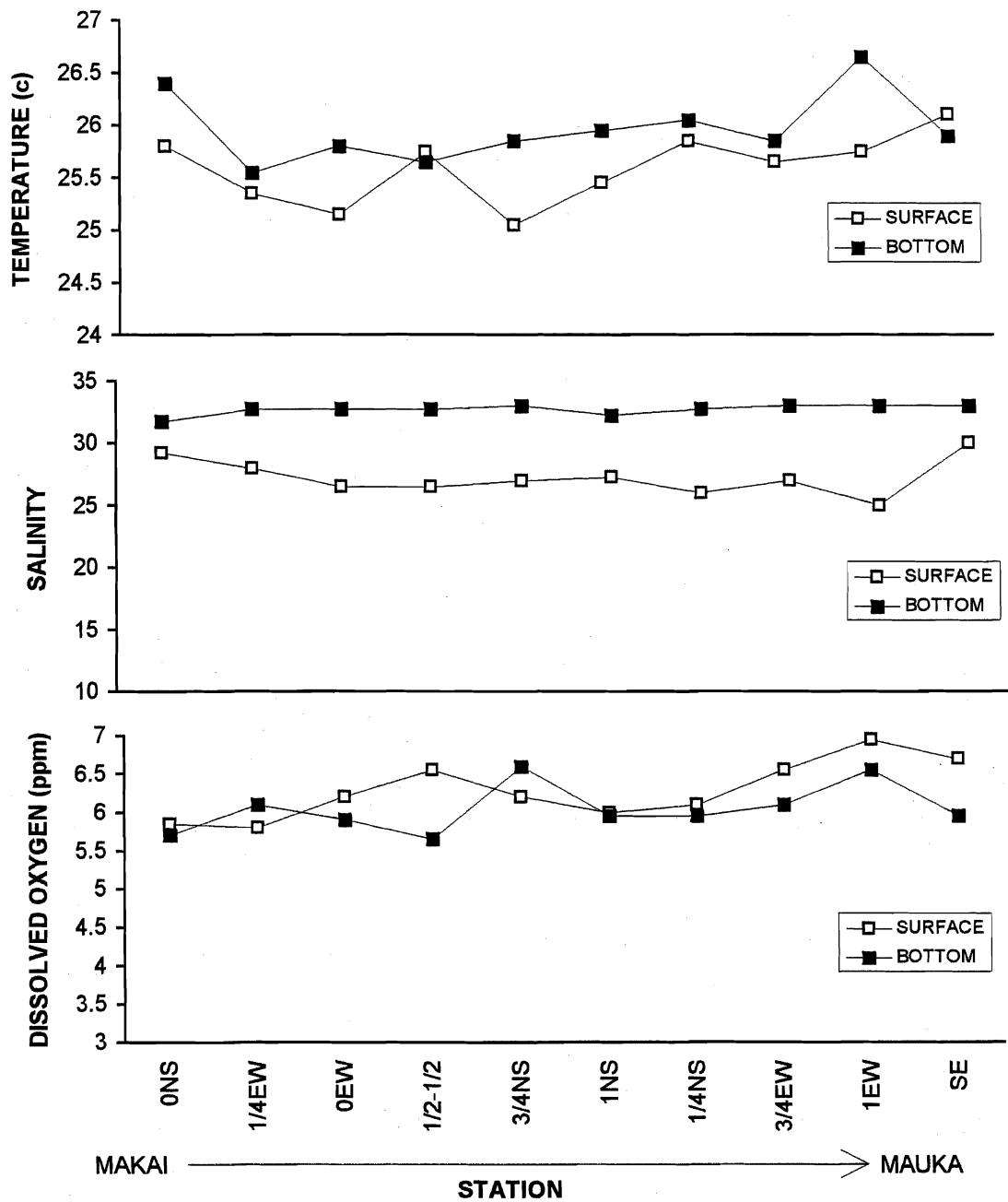


Figure 3. Mean values for temperature ($^{\circ}\text{C}$), salinity, and dissolved oxygen measured at just below the surface and 30 cm from the bottom of Kaloko fishpond during high tides on 12/15/97 (6pm) and 12/16/97 (6am).

An interesting characteristic of the fishpond wall as it is currently constructed is that the majority of the salt water entering the pond does so only during high tide events, by breaching a relatively low spot at the northern end of the wall. We placed a measuring rod in the south-western portion of the pond and periodically recorded stage (height of water) over a twenty-four hour period which included a "low" high tide (16 cm) and a "high" high tide (60 cm). Water level in the pond showed little change in response to the "low" high tide, but mirrored the change in sea level during the "high" high tide (Figure 4).

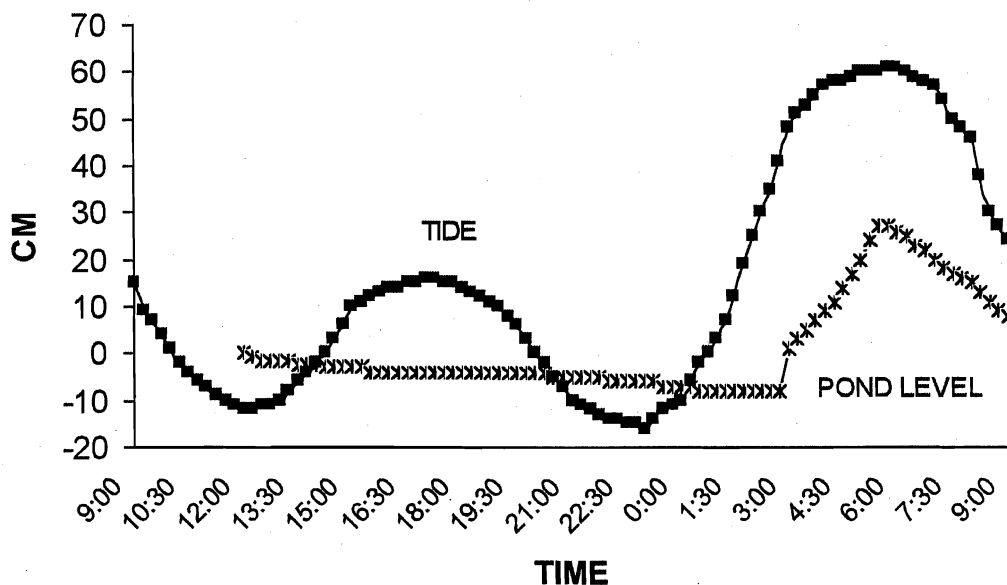


Figure 4. Changes in pond level as a response to tidal fluctuation (data from 9 am 12/15/97 to 9am 12/16/97).

In addition to measuring actual changes in water chemistry, measuring water level in the pond as it relates to tidal fluctuations is a simple and effective way to monitor seawater influence on the pond. At present, large influxes of seawater to the pond occur only during higher tides. An alteration in seawall structure and the restoration of the makaha (sluice gate) will potentially increase both the quantity and duration of salt water flow into the fishpond.

Biota

Fish were surveyed using a number of methods including gill nets, seines, dip nets, traps, hook and line, and visual observation with mask and snorkel or from the shore. Invertebrates were collected with traps, dip nets and by hand. It is recommended that monitoring studies at Kaloko likewise utilize a variety of methods to survey the biota. Most importantly because different methods are more effective for different species. Also, it is useful to have both quantitative and qualitative assessments, and different types of collecting methods are used to obtain these two types of results.

The most effective method for identifying marine fish species during this study (especially reef fish) was simple observation from the shoreline. Colorful reef fish such as the raccoon butterfly fish or *kika kapu* (Chaetodon lunula) and convict tang or *manini* (Acanthurus sandvicensis)

are easily identifiable from the shore. Snorkeling in the pond is another method of direct observation, but visibility was too low during our survey for this to be effective.

Gill netting was mainly effective for larger fish like *ama'ama* (Mugil cephalus) and *awa* (Chanos chanos). For example, one sweep of the gill net in the western corner of the pond captured three *awa* (37.5 cm SL, 39.5 cm SL and 38 cm SL), each weighing over 1000 grams. Fish may not survive gill netting, so it is best used when specimens need to be retained (such as for tissue analysis or gut content analysis). The predatory barracuda or *kako* (Sphyrna barracuda) was easily captured using hook and line. Gut content analysis of one barracuda produced an unidentifiable 5 cm fish.

Overall, species composition was quite similar between the 1991 (Chai) survey and the current study. Some different marine species were noted during the two surveys, but this is not surprising as the fish would be expected to move in and out of the pond. One interesting difference, though, was that no squirrel fish (Holocentridae) or goat fish (Mullidae) were observed during the 1997 survey. It is possible that they simply weren't present, or that they were not detected because of choice of sampling methods. Chai (1991) snorkeled the pond, while we did not. Also, the majority of the biota sampling was conducted between dawn

and dusk during this study (1997), while Chai (1991) also conducted nighttime sampling, a time when squirrel fish and goat fish are more active.

Although an overnight trap line (of six traps) across the width of the pond captured no fish, use of minnow traps was shown to be an effective quantitative method for collecting shrimp. In addition to number of shrimp; size class, sex and reproductive status can be determined. Two minnow traps placed overnight in the south-east corner of the pond collected 71 glass shrimp or *opae huna* (*Palaemon debilis*), of which seven were gravid (carrying eggs). Four other traps set along the sea wall and south shore of the pond collected no animals. An earlier study (Brasher 1996) in Kaloko fishpond also showed the traps to be effective for catching introduced poeciliids (*Gambusia affinis* and *Poecilia vittata*).

Interestingly, although empty shells were scattered around the shoreline, almost no live adults or juveniles of the pond snail *Theodoxus cariosus* (*hapawai*) were observed during our study. Freshly laid eggs of *I. cariosus* were, however, noted on rocks at the western corner of the pond. Further investigation is required to determine if there is a seasonal component to the presence of this pond snail. An alternative hypothesis might be that the pond is presently too saline to support a population of *I. cariosus*. A second estuarine neritid snail, *Theodoxus vespertina*, is found in

other ponds at Kaloko-Honokohau National Historical Park but has not been reported for Kaloko fishpond.

Simple laboratory tests can be used to determine the salinity tolerance of different estuarine species. For example, in two separate trials we placed 20 *opae huna* (*Palaemon debilis*) in aquaria either filled with freshwater or seawater. Those placed in freshwater expired within 30 minutes while those placed in seawater were still living after two months. Similar tests could be repeated with other species of interest such as oysters (*Isognomen*) or neritid snails (*Theodoxus cariosus*).

A comprehensive biological monitoring program at Kaloko fishpond should include routine quantitative surveys of a few selected taxa and less frequent qualitative surveys providing a species list for the pond. Inclusion of quantitative surveys is crucial for statistically valid analysis of abundance and stability of "critical species" during and following the restoration of Kaloko Pond as an active fishpond. Initial monitoring should focus on the edible fish species that will be raised in the fish pond, which potentially include milkfish or awa (*Chanos chanos*), mullet or *ama'ama* (*Mugil cephalus*) and flagtail or *aholehole* (*Kuhlia sandvicensis*). Three additional species; a shrimp (*Palaemon debilis*), a snail (*Theodoxus cariosus*), and a damselfly (*Megalagrion xanthomelas*) are rare species

that could be affected by a change in the pond circulation and salinity and consequently should be included in initial monitoring.

Very little work has been done on the native estuarine pond species such as *T. cariosus* and *P. debilis* in Hawai'i. Kaloko fishpond provides an ideal setting for studying life history, migratory patterns and habitat requirements of such species. Results of these type of studies will provide valuable additional information for the management of Hawai'i's unique anchialine pond systems.

Monitoring Critical Resources

Considering potential constraints upon availability and training of staff for the monitoring of Kaloko fishpond during and following its restoration, a sample monitoring strategy is recommended below. Refinements to this strategy should be made by the biologist hired to implement the monitoring program, based upon management decisions concerning stocking, feeding, sediment removal and predator control, all of which could affect basic fishpond function. Monitoring should include physical, chemical, and biological parameters, with both qualitative and quantitative approaches used to assess the status of the biota. A number of fishponds have recently been re-established on Maui and Moloka'i and the information learned during these projects could help the Park in developing its restoration and management strategy for Kaloko Pond.

Initial quantitative biological monitoring should focus on the "critical species" discussed in this report, including the edible fish species which will be raised in the pond and the native invertebrates that could be affected (either positively or negatively) by a change in the current pond structure. Quantitative measures would include counts along transects or quadrats, as well as use of traps or nets (seine hauls or gill nets). Size of all animals should be reported, as well as sex and reproductive status when available.

A monthly sampling schedule should be established for monitoring the condition of Kaloko fishpond. Physical/chemical parameters and biological parameters would be evaluated on alternative months. At present, an adequate baseline of chemical and biological data exists to provide a foundation for future studies. Summaries of this data are available in this report, as well as in reports by Bhambare (1997), Brock and Kam (1997) and Chai (1991). Additional recommendations for monitoring the pond can be found in the West Hawaii Coastal Monitoring Task Force report (1992) which discusses a long term monitoring plan for aquatic resources along the Kona coast, including Kaloko-Honokohau National Park.

Physical Parameters

An interesting characteristic of the fishpond wall as it is currently constructed is that the majority of the salt water entering the pond does so only during high tide events, by breaching a relatively low spot at the northern end of the wall. Placement of the *makaha* may be critical to the flow characteristics, and consequently sediment load of the fish pond (Ertekin et al. 1996). If circulation is weak, water movement may not be sufficient to inhibit silt accumulation, which in turn significantly reduces the efficiency of fishpond operations. At present, the northern end of Kaloko Pond has a high level of siltation, enhancing its value as habitat for waterbirds (M. Morin, personal communication) but decreasing its value for fish culture.

Numerical tidal-circulation simulations have been developed which can be used to evaluate sluice gate placement and the potential effects on pond circulation (Ertekin et al. 1996). The use of such models prior to the restoration of the sluice gate may provide valuable information for managing the fish pond. For example; two possibilities have been proposed to improve tidal circulation within fishponds (Sundararaghan 1997), and consequently enhance productivity as a fish growing system. First, the jet that occurs near the sluice gate entrance could be directed

in such a way to increase circulation in the regions of low circulation away from the sluice gate. Alternatively, using two sluice gates that could be opened and closed at different times would allow the pond to be filled through one gate during the flood tide and emptied through the other gate during the ebb tide.

Physical parameters to be monitored at Kaloko Pond should include temperature, tidal influence (water level) and degree of siltation. Siltation may be managed by initial dredging of the pond, and /or improved tidal circulation (as discussed by Sundararaghan 1997). The placement of several continuous temperature loggers in the pond would provide a relatively inexpensive way to collect useful information on changes in temperature (indirectly indicating relative input of saltwater versus freshwater).

Chemical Parameters

Measurement of basic water chemistry parameters (salinity, pH, dissolved oxygen, and conductivity) in Kaloko fishpond should be relatively inexpensive and also not require a large amount of time. Initial costs would include appropriate handheld water quality meters and two kayaks. Results would provide information on relative amounts of groundwater versus seawater entering the pond, as well as the degree of

mixing occurring. Two days, every other month (one during high tide and one during low tide) sampling of basic physical and chemical parameters in the pond over a twenty-four hour cycle would provide information on diel and seasonal fluctuations in water quality, and produce data comparable to previous studies.

During this study, water chemistry parameters were measured both near the surface and near the bottom of the pond. The final restored structure of the *makaha* and *pani* will determine the most effective strategy for making water chemistry measurements. Bhambare (1997) recommends that if the pond has continual open access to the sea, then water chemistry measurements should be taken near the surface, as the deeper depths may not show much variation. If the pond does not have open flow to the sea, then the freshwater layer may be relatively deep, and measurements can be taken at deeper depths.

Due to the expense of laboratory analysis, a less frequent schedule for monitoring nutrient and contaminant levels would be necessary. For example, a yearly evaluation of these parameters should be adequate, unless other information becomes available suggesting a possible threat to water quality at Kaloko Pond. There is a concern about potential contamination of fish tissue if Kaloko Pond is maintained as a fishpond and there is human consumption of the fish. Brock and Kam (1997) screened

for a number of potential contaminants of bed sediment and tissue in Aimakapaa Pond (located south of Kaloko Pond, also within the boundaries of Kaloko-Honokohau National Historical Park), and reported no significant findings of contamination at the available levels of detection. They did find elevated levels of arsenic, mercury and manganese in the tissue samples, but attribute this to inputs from volcanic sources.

Biological Parameters

Surveys of the pond biota should be conducted every other month (alternating with the physical/chemical analyses). Different sampling methods result in different species being collected and it is recommended that a combination of methods, including both quantitative and qualitative approaches be utilized in the monitoring program. Quantitative methods result in data that can be statistically analyzed to provide an objective assessment of change over time, and should be used for initial assessments and throughout the monitoring period.

Traps, counts along transect lines (or within quadrats), and abundances from seine hauls or gill nets are examples of accepted quantitative methods that can be used to survey Kaloko Pond. Although

transects were not used in any of the surveys here, they may be especially useful for monitoring sessile species such as molluscs.

Qualitative methods, such as walking along the shore and turning over rocks, and conducting pond-wide searches using a variety of methods, often allow for the collection of a wider range of species and/or can target individual species. Qualitative methods will provide an overview of species present and may be especially sensitive to rarer organisms.

Initial quantitative biological monitoring should focus on the "critical species" discussed in this report, including the edible fish species which will be raised in the pond (for example; awa (Chanos chanos), ama'ama (Mugil cephalus) and aholehole (Kuhlia sandvicensis)) and the rarer native invertebrates; a shrimp (Palaemon debilis), a snail (Theodoxus cariosus), and a damselfly (Megalagrion xanthomelas) that currently or potentially utilize Kaloko Pond. If visibility allows, the fish should be counted using a transect method. Otherwise, quantitative abundance estimates may be made from seine hauls or using a gill net. Shrimp are easily trapped with a minnow trap while snails and damselflies may be counted using either transects or quadrats. For fish, shrimp and snails, size, sex, and reproductive status should be recorded. Larval and adult damselflies should be surveyed separately.

Decisions concerning species selected for initial culture, methods of stocking the pond, sediment control, potential supplementary feeding of the food fish or fertilization of the pond, and possible predator removal will guide the actual monitoring process. Likewise, management decisions concerning purpose of the fish pond for potentially conflicting uses (for example; fish culture, traditional fishing activities, protection of endangered birds, and protection of potentially endangered invertebrates) will provide direction for the focus of the monitoring activities at Kaloko Pond during and following restoration of the fishpond.

In conclusion, the focus of monitoring to evaluate the impacts of restoration of Kaloko Pond as a functioning fishpond, should include physical (temperature, tidal fluctuation, and siltation), chemical (oxygen, pH, salinity, and conductivity) and biological (edible fish to be raised in the pond and rare invertebrates that may be affected by the planned restoration) components. While the final monitoring protocol must be based upon management decisions concerning methods of restoration and maintenance of the fishpond, suggestions for the initial monitoring strategy are summarized in this report. As restoration of the pond progresses, the situation can be evaluated, based in part upon data collected during the monitoring, and management strategies for the fishpond can be refined as necessary.

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